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HYDROGRAPHY OF THE LACCADIVES OFFSHORE WATERS[1]

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INTRODUCTION

THE importance of the waters around the Laccadives ' with their special ecological conditions and their influence on the adjacent coastal waters of the mainland of India ' has been indicated in an interesting review of the oceanographical investigations in the eastern section of the Arabian Sea by Jones (1959). The Laccadives region is particularly interesting to the oceanographer, because of the presence of the submarine ridge—the Laccadives-Chagos Ridge—which has a great influence on the circulation of the water masses in this part of the Indian Ocean. The ridge contributes, to some extent, to the enrichment of the upper waters of the mid-ocean as has been suggested by Cooper (1957). . To the fishery investigator, this region is equally interesting, as it is known to support a rich fishery, particularly of the pelagic type. A detailed hydrographic survey of this region is, therefore, considered necessary as it would help to throw light on several problems of oceanographical and fishery interest.

An account of the distribution of one of the main parameters—dissolved oxygen—has already been presented (Jayaraman *et al.*, 1959) and this has given us some preliminary idea of the hydrographical features of this region. The present paper is to be considered as more or less an extension of the same with more details regarding the distribution of other factors and the pattern of circulation and water movements derived therefrom. The data discussed in this paper refer to the two cruises made in the month of April (1959) which forms a transition between the end of the North-east monsoon and the commencement of the South-west monsoon and is expected to depict more or less stable conditions in this environment.

COLLECTION OF DATA AND MODE OF TREATMENT

Fig. 1 shows the geographical location of the 25 hydrographic stations. Water samples for salinity and dissolved oxygen and temperature data were collected at all the international depths down to 500 metres from these hydrographic stations. All are deep water stations, the depths in each of them exceeding 1,500 metres. The stations which have been occupied have been grouped into six sections covering the entire region and the vertical distributions of the various parameters in all

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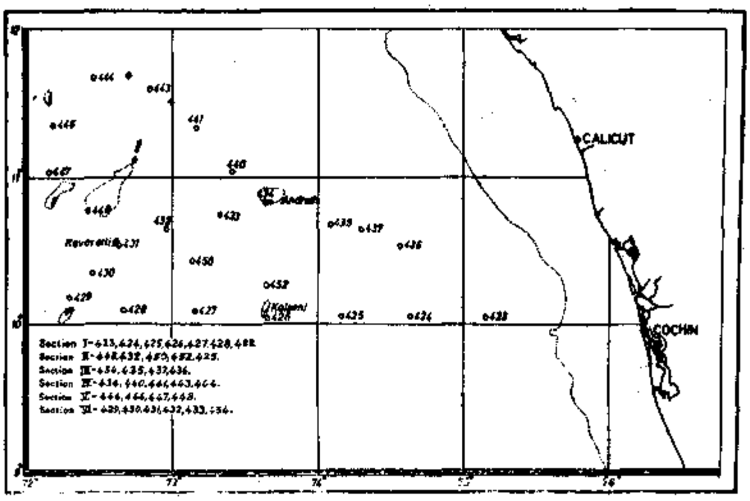


FIG. 1. Chart showing the geographical location of the oceanographic station in the 'Laccadive region'.

these sections have been worked out. Computations of geopotential anamolies have also been made with the available data and with reference to 500 decibar surface, but graphic representations of the same have not been attempted as the number of stations worked is too small to facilitate contouring.

General Characteristics of the Distributions of Parameters

(a) *Temperature*

All the vertical sections (Figs. 2 to 7) have been drawn from the readings of the reversing thermometers after applying the appropriate corrections. The section due west of Cochin (Section I) covers the maximum distance in the area and could be considered as a more or less representative one for purposes of discussion. The positions of the isotherms show that a uniform temperature of about 30°C is maintained in the upper layers. As the whole region has been covered in two cruises, it may be seen that those stations which have been worked in the latter part of the month have slightly higher temperature values. The upper 50 metres are seen to be more or less isothermal. Decrease begins below 50 metres and the thermal discontinuity is observed at about 75-80 metres. The thermocline is very sharp and is seen to have a thickness of nearly 50 metres or even more at a few stations. The deeper layers exhibit more or less uniform distribution of temperature. The isotherms show characteristic 'doming' and 'depressions' which have probably been caused by extensive water movements. This point is, however, discussed in greater detail in a later section of this paper.

(b) *Salinity*

The surface values are rather low and there is a steady increase downwards. The salinities are slightly higher in the more northern stations and are in accordance with the distribution of surface salinity in different latitudes as described by

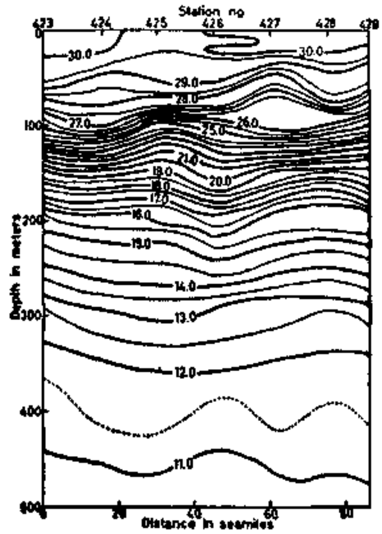


FIG. 2. Vertical Temperature distribution in Section I; In this and the following Sections thick curves represent integral values of Temperature and thin curves represent values at 0.5°C interval.

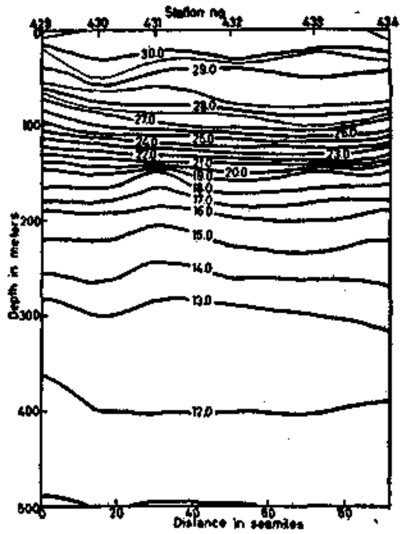


FIG. 3. Vertical Temperature distribution in Section II.

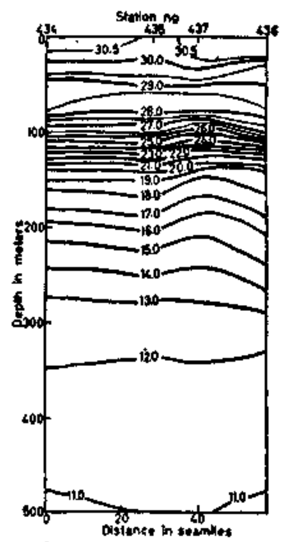


FIG. 4. Vertical Temperature distribution in Section III.

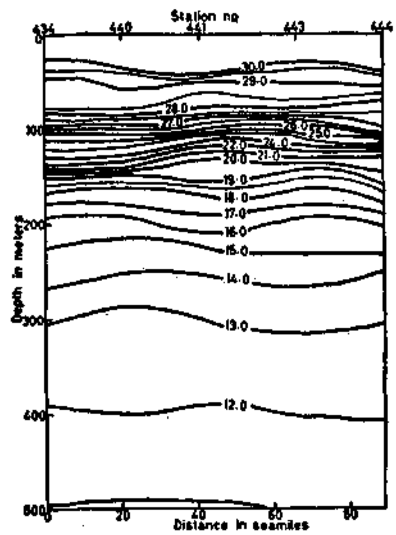


FIG. 5. Vertical Temperature distribution in Section IV.

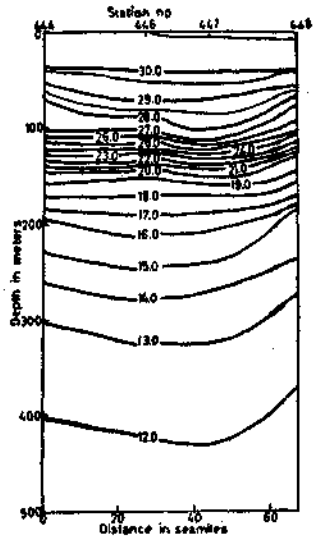


FIG. 6. Vertical Temperature distribution in Section V.

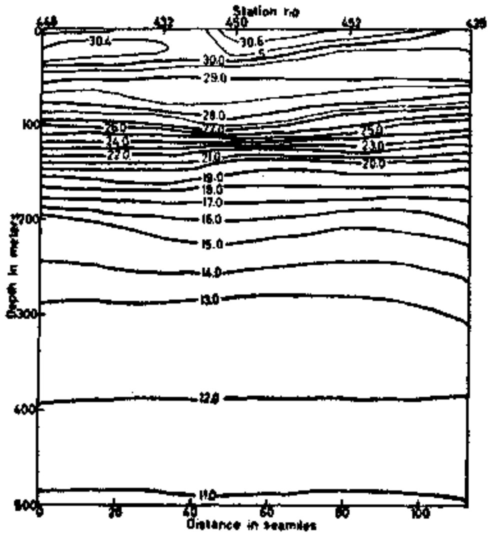


FIG. 7. Vertical Temperature distribution in Section VI.

Sverdrup (1942, p. 124). The most interesting feature about the sub-surface distribution of salinity is the occurrence of salinity maximum at about 100 metres in practically all the stations (see figs. 8 to 13). A tongue of highly saline water with a thickness of about 50 metres is observed to be present and the salinity maximum is seen to occur within this tongue.

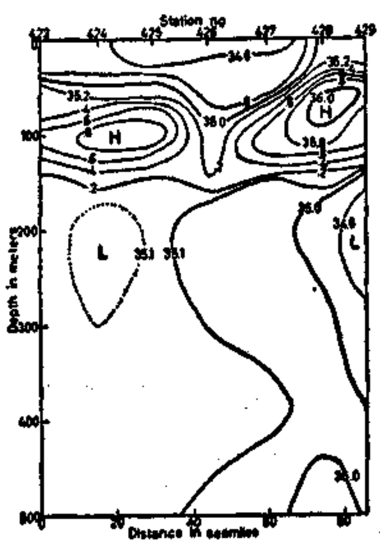


FIG. 8. Vertical distribution of Salinity in Section I.

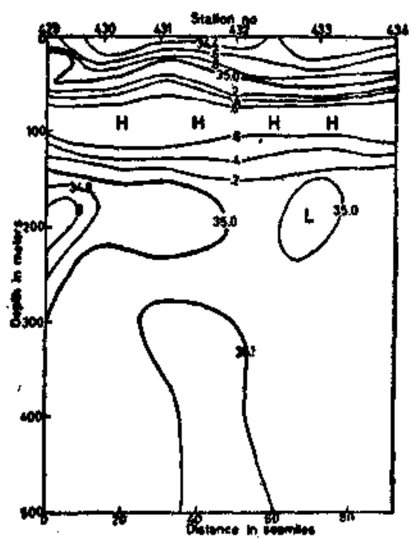


FIG. 9. Vertical distribution of Salinity in Section II.

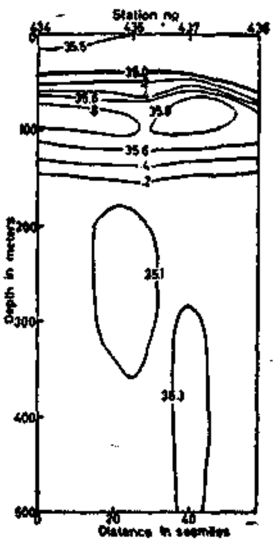


FIG. 10. Vertical distribution of Salinity in Section III

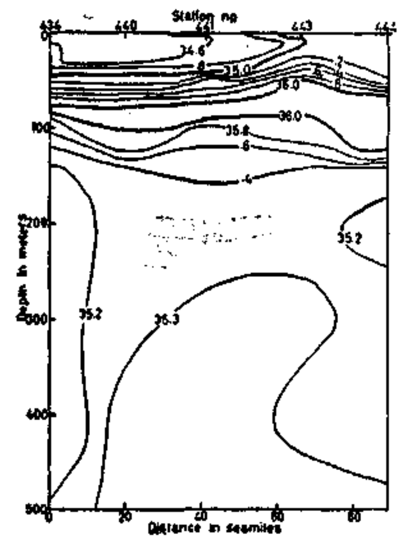


FIG. 11. Vertical distribution of Salinity in Section IV.

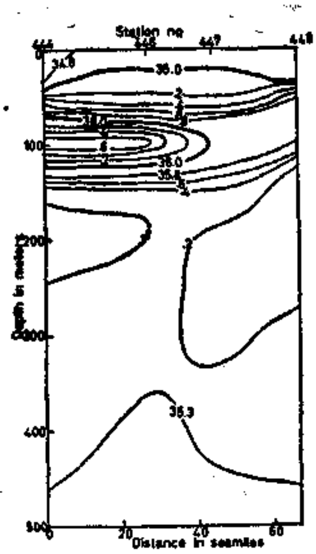


FIG. 12. Vertical distribution of Salinity in Section V.

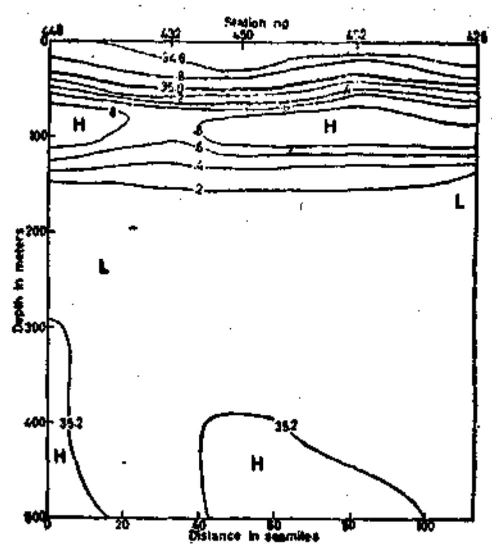


FIG. 13. Vertical distribution of Salinity in Section VI.

In general, in the surface layers, the salinity distribution is more or less uniform as could be seen from the nearly horizontal and unbroken nature of the isohalines. Below the layer of salinity maximum there is a steady decrease of salinity. In these layers the isohalines exhibit a peculiar trend, being nearly vertical in most cases. This is particularly evident in Section I where the 35.10°/₀₀ isohaline extends nearly in a vertical plane from just below the thermocline and down to 500 metres. Isolated cells of low salinity are also seen to be present.

The occurrence of a salinity maximum at or about 100 metres is considered to be characteristic of the tropical areas of the oceans and several explanations have been offered. In the present instance, one of the possibilities to be considered is the Red Sea influence. Clowes and Deacon (1935), while discussing the distribution of salinity in a section along the east coast of Africa, state that the Red Sea water sinks to a depth of 500 metres at 8°N. latitude as a high saline tongue and is detectable as far as 40°S. latitude at a depth of 1,250 metres. In view of its high density as shown by these authors it does not seem reasonable to postulate that the salinity maximum at 100 metres is caused by the sinking and spreading of the Red Sea water. It may at best be considered as a secondary effect due to a 'random scattering of the disintegrated elements' of the Red Sea water as has been indicated by Tait (1957) while describing the Gulf of Gibraltar water intrusions in the Faroe-Shetland channel. It is more probable that the salinity maximum as observed by us, is due to the sinking and spreading of the waters of the northern portion of the Arabian Sea, the surface salinity of these waters having been shown to be very high (Jayaraman and Gogate, 1957).

(c) Density

The vertical distributions of density in the various sections are shown in Figs. 14 to 19. The sigma-t surfaces, like the isotherms, show the characteristic 'domings' and 'depressions' and these are much more marked and present practically at all levels.

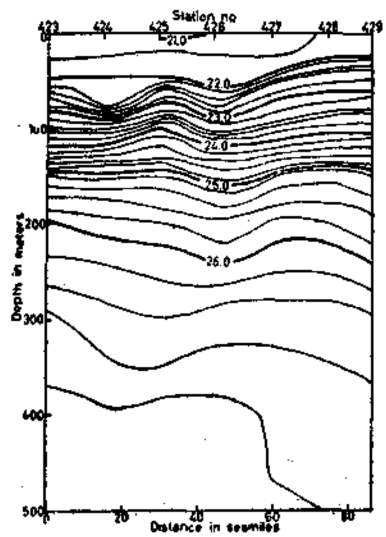


FIG. 14. Vertical distribution of density (Sigma-T) in Section I. In this and the following sections thick curves represent integral values of Sigma-T, and thin curves represent values at 0.2 g./L interval.

An examination of the slopes of the sigma-t surfaces particularly at the sub-surface layers gives one the impression that there are water movements of great

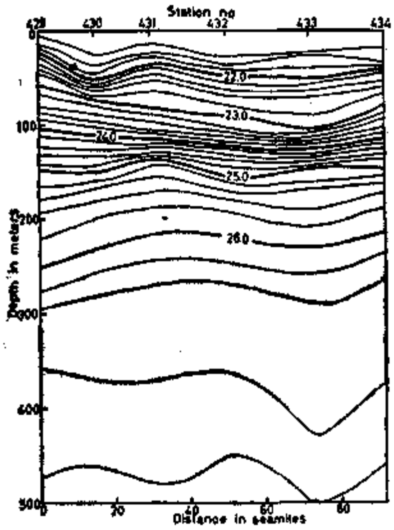


FIG. 15. Vertical distribution of density in Section II.

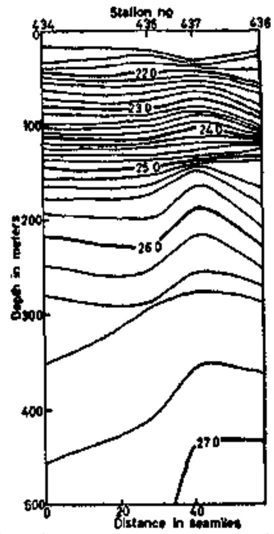


FIG. 16. Vertical distribution of density in Section III.

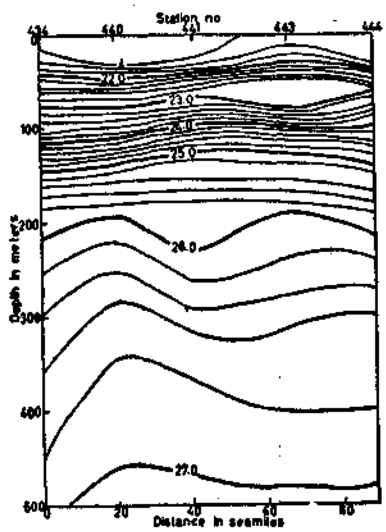


FIG. 17. Vertical distribution of density in Section IV.

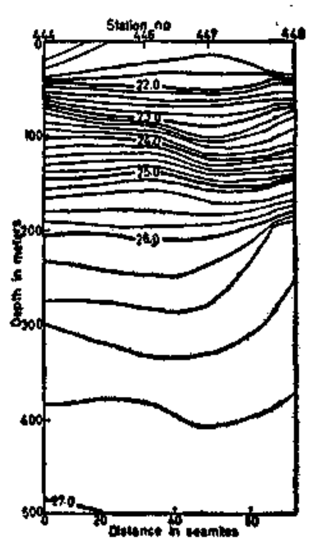


FIG. 18. Vertical distribution of density in Section V.

intensity at the deeper layers. According to Deacon (1937) the slopes of the density surfaces are generally prone to give an exaggerated picture of the strength of the deep currents and the slopes of the layers involve several other factors besides the movement of a particular water mass. In the present instance it was thought desirable to examine in detail the computed geopotential anamolies and to find out

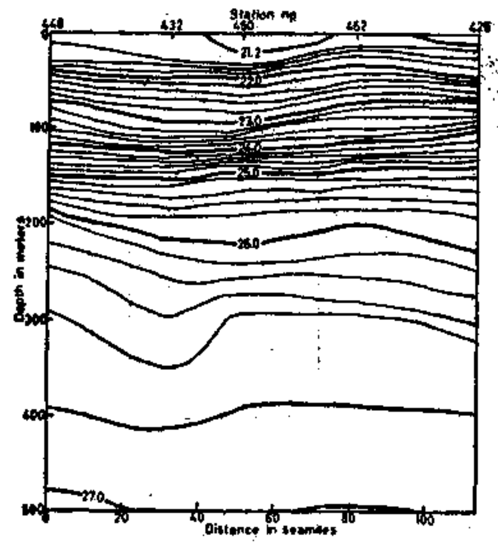


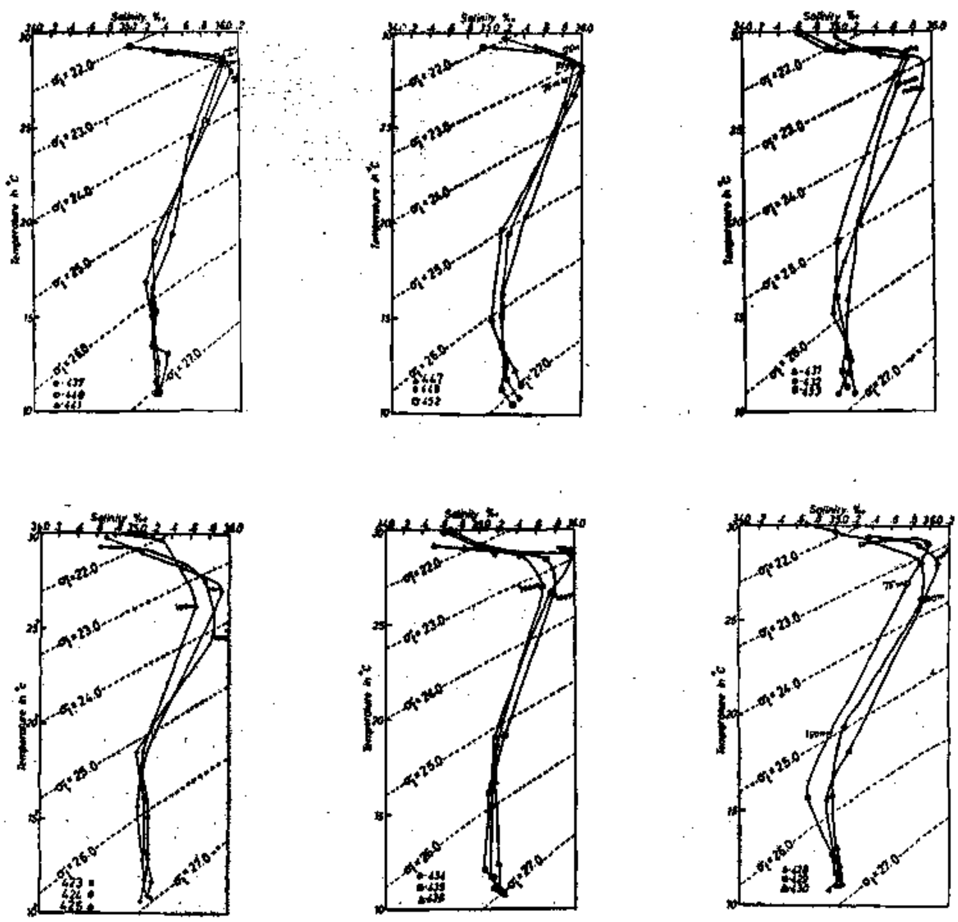
FIG. 19. Vertical distribution of density of Section VI.

whether there are any appreciable deep water movements and if so whether we could get any idea of the intensity of such movements. The inferences drawn from these studies could be briefly stated as follows : The main type of motion that is detectable is the circulatory motion and it is seen to be present around each of the islands. The pattern of circulation is more or less the same. A fairly anticyclonic motion (clockwise circulation) is seen to be present around the islands Kalpeni, Kavarathi and Androth. This type of motion is seen to be present from surface down to the discontinuity layer. At the deeper levels the circulation is completely reversed, the motion being cyclonic in most of the stations. The *Hugh M. Smith* cruises in the Hawaiian offshore waters have also revealed the presence of similar circulatory movements round the islands (McGary, 1955 ; Seckel, 1955). Whatever be the detailed pattern of circulation, it is fairly clear that in the Laccadives region, the waters are kept circulating in the vicinity of the islands most of the time. There does not seem to be any appreciable degree of lateral transport of the water masses at least during this season.

Temperature-Salinity Relationships and Inferences Regarding the Different Water Masses in this Region

The T.-S. diagrams for a few selected stations are given in figs. 20 to 25. In discussing the relationships the surface waters and sub-surface waters down to 30 metres have been omitted as they are very much influenced by local conditions, biological activity etc. The water masses below this level of 30 metres could be classified in the same way as has been done by Sastry (1960) for the waters along the Kerala coast. The three main types as observed by us are:

(1) The water mass down to 75-100 metres is characterized by a rather sharp salinity gradient with a very small temperature range. The sigma-t values range



FIGS. 20—25. Temperature-Salinity relationships of a few selected stations.

between 21.00 and 23.00. Sastry while describing a similar water mass in the Kerala Coastal waters, states that it is this water mass which participates most in the upwelling and sinking phenomena. This probably corresponds to the Arabian Sea upper sub-surface water described by Sastry.

(2) The second one is characterized by a steep temperature gradient with a salinity range hardly exceeding 0.8°/₀₀. The sigma-t values lie between 23.00 and 25.00. This seems to be much better defined than the first one. This could be termed as the Arabian Sea Lower Sub-surface water.

(3) The water mass below 200 metres is characterized by having small temperature and salinity gradients. In some stations, it almost appears like isohaline water. From an examination of its temperature and salinity characterist as well as its density range, this water mass could be identified as the Indian Ocean Equatorial water (Sverdrup, 1942).

Remarks Concerning the Circulation of Water Masses and the Productivity of the Laccadives Region

The geostrophic pattern of circulation derived in the preceding paragraphs studied in conjunction with the vertical distribution of dissolved oxygen indicated in the previous paper (Jayaraman *et al.*, 1959) brings out certain interesting conclusions regarding the water movements and the productivity of the Laccadives region. In this connection it would be worth while to refer to the interesting paper by Richards (1957), wherein it has been stated that the oxygen-minimum layer especially in the tropical waters is closely related to the organic productivity of the waters and the great differences in the depths at which the oxygen-minima are found are attributed to the differences in the productivity. It is observed that in these waters the oxygen-minimum layer is several metres thick and the upper level of this layer is seen to be present at 150 metres. (It is generally found in the open parts of the ocean at about 300 metres). Both these observations more or less conclusively point to a rather high level of productivity of the Laccadives waters. It may be seen that the circulatory water movements help to maintain the highly productive waters in the vicinity of the islands for a considerable length of time. It is also indicated as a possibility that this circulatory motion helps to keep the fish eggs and larvae in the highly productive waters of this region, thereby providing them a favourable environment. It may thus be stated that one of the most significant relationships between the animate environment and the inanimate (physical) environment is seen to have been fairly well established in the waters of the Laccadives region.

Summary

An account of the main hydrographical features of the Laccadives offshore waters is presented. The results relate to the period of the year when stable conditions are expected to exist in the environment. The temperature distributions indicate the presence of a more or less isothermal water down to 50 metres. The discontinuity layer is observed to be between 75 and 150 metres. A salinity maximum is seen to occur within a tongue of high saline water at about 100 metres. From the nature of the density surfaces and the computed geopotential anomalies, it is inferred that there are circulatory water movements around the islands at practically all levels down to 500 metres; the motion is anticyclonic in the upper 100 metres and reverse of that below that level. The importance of such circulatory movements in keeping the highly productive waters around the islands is indicated.

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